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1. **Your reference** — 85.74444/006

2. **Patent application number** *(The Patent Office will fill in this part)* — 25 APR 2001

0110149.2

3. **Full name, address and postcode of the or of each applicant** *(underline all surnames)*

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25APR01 E624623-1 D00027
P01/7700 0.00-0110149.2

Patents ADP number *(if you know it)* — 6996102001

If the applicant is a corporate body, give country/state of incorporation — UK

4. **Title of the invention** — Mass spectrometers and methods of mass spectrometry

5. **Name of your agent** *(if you have one)* — Frank B. Dehn & Co.

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

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Patents ADP number *(if you know it)* — 166001

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
GB	0029088.2	29/11/00
GB	0109760.9	20/04/01

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8. **Is a statement of inventorship and of right to grant of a patent required in support of this request?** *(Answer 'Yes' if:*
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Yes

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Claim(s)	11
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Any other documents *(please specify)*	-

11. I/We request the grant of a patent on the basis of this application.

Signature Date 25 April 2001

12. Name and daytime telephone number of person to contact in the United Kingdom

P.M. Jeffrey
01273 244200

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MASS SPECTROMETERS AND METHODS OF MASS SPECTROMETRY

The present invention relates to mass spectrometers and methods of mass spectrometry.

Ion guides comprising rf-only multipole rod sets such as quadrupoles, hexapoles and octopoles are well known.

An alternative type of ion guide known as an "ion funnel" has recently been proposed by Smith and co-workers at Pacific Northwest National Laboratory. An ion funnel comprises a stack of ring electrodes of constant external diameter but which have progressively smaller internal apertures. Accordingly, a dc voltage/potential gradient must be applied along the length of the ion guide in order to urge ions through the ion funnel otherwise the ring electrodes would act as an ion mirror.

A variant of the standard ion funnel arrangement is disclosed in Anal. Chem. 2000, 72, 2247-2255 and comprises an initial drift section comprising ring electrodes having constant internal diameters and a funnel section comprising ring electrodes having uniformly decreasing internal diameters. A dc voltage gradient is applied across both sections in order to urge ions through the ion funnel.

Ion funnels suffer from a number of problems and have not therefore been successfully employed in commercial mass spectrometers to date.

The application of a dc voltage gradient to the ion funnel causes the ion funnel to have a narrow bandpass transmission efficiency i.e. the ion funnel may, for example, only efficiently transmit ions having mass to charge ratios ("m/z") falling within a narrow range e.g. $100 < m/z < 200$. Reference is made, for example, to Figs. 5A and 5B of Anal. Chem. 1998, 70, 4111-4119 wherein experimental results are presented comparing

observed mass spectra obtained using an ion funnel with that obtained using a conventional ion guide. The experimental results show that both relatively low m/z and relatively high m/z ions fail to be transmitted by the ion funnel. Reference is also made to pages 2249 and 2250 of Anal. Chem 2000, 72, 2247-2255 which similarly recognises that ion funnels suffer from an undesirably narrow m/z transmission window.

Another problem with ion funnel ion guides is that they require both an rf voltage and a dc voltage gradient to be applied to the ring electrodes. However, the design and manufacture of a reliable power supply capable of supplying both an rf voltage and a dc voltage gradient which is decoupled from the rf voltage is a non-trivial matter and increases the overall manufacturing cost of the mass spectrometer.

It is therefore desired to provide an improved ion guide.

According to a first aspect of the present invention, there is provided a mass spectrometer as claimed in claim 1.

The preferred embodiment comprises a plurality of ring electrodes wherein most if not all of the ring electrodes have substantially the same size and preferably circular shaped internal apertures. Such an arrangement is referred to hereinafter as an "ion tunnel" in contrast to ion funnels which have ring electrodes with internal apertures which become progressively smaller in size.

One advantage of the preferred embodiment is that a dc voltage gradient is not and does not need to be applied to the ion guide. Accordingly, the ion guide according to the preferred embodiment does not suffer from a narrow or limited mass to charge ratio transmission efficiency which is inherent with ion funnel arrangements. Furthermore, the resulting power supply for the ion guide can be significantly simplified compared with that required for an ion funnel thereby

saving costs and increasing reliability.

An additional advantage of the preferred ion tunnel is that it has been found to exhibit an approximately 25% improvement in ion transmission efficiency compared with a conventional multipole, e.g. hexapole, ion guide. The reasons for this enhanced ion transmission efficiency are not fully understood, but it is thought that the ion tunnel may have a greater acceptance angle and a greater acceptance area than a comparable multipole rod set ion guide.

The preferred ion guide therefore represents a significant improvement over other known ion guides.

Various types of ion optical devices other than a ring electrode ion guide are known including multipole rod sets, Einzel lenses, segmented multipoles, short (solid) quadrupole pre/post filter lenses ("stubbies"), 3D quadrupole ion traps comprising a central doughnut shaped electrode together with two concave end cap electrodes, and linear (2D) quadrupole ion traps comprising a multipole rod set with entrance and exit ring electrodes. However, such devices should not be construed as representing a ring electrode ion guide within the meaning of the present application.

Preferably, a second rf-only ion guide is disposed in the second vacuum region, the second ion guide comprising a second plurality of ring electrodes. Preferably at least 90%, further preferably 100%, of the second plurality of ring electrodes have substantially the same size internal apertures and/or are arranged and adapted to be maintained at substantially the same dc voltage or are connected to a common dc voltage supply.

Preferably, either the first and/or second ion guides comprise at least 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, 60, 70, 80, 90 or 100 ring electrodes.

Preferably, the first ion guide is maintained at 0-2 V dc, further preferably 0-1 V dc, above the dc potential of the first differential pumping aperture.

Preferably, the second ion guide is maintained at

0-2 V dc, further preferably 0-1 V dc, above the dc potential of the second differential pumping aperture.

Preferably, the pressure in the first vacuum chamber is arranged to be maintained at a pressure selected from the group comprising: (i) ≥ 0.5 mbar; (ii) ≥ 0.7 mbar; (iii) ≥ 1.0 mbar; (iv) ≥ 1.3 mbar; (v) ≥ 1.5 mbar; (vi) ≥ 2.0 mbar; (vii) ≥ 5.0 mbar; (viii) ≥ 10.0 mbar; (ix) 1-5 mbar; (x) 1-2 mbar; and (xi) 0.5-1.5 mbar. A pressure ≥ 1.0 mbar is particularly preferred.

Preferably, the pressure in said second vacuum chamber is arranged to be maintained at a pressure selected from the group comprising: (i) 10^{-3}-10^{-2} mbar; (ii) ≥ 2 x 10^{-3} mbar; (iii) ≥ 5 x 10^{-3} mbar; (iv) ≤ 10^{-2} mbar; (v) 10^{-3}-5 x 10^{-3} mbar; and (vi) 5 x 10^{-3}-10^{-2} mbar. A pressure in the range 10^{-3}-10^{-2} mbar is particularly preferred.

Preferably, the first plurality and/or the second plurality of ring electrodes have internal diameters or dimensions selected from the group comprising: (i) ≤ 5.0 mm; (ii) ≤ 4.5 mm; (iii) ≤ 4.0 mm; (iv) ≤ 3.5 mm; (v) ≤ 3.0 mm; (vi) ≤ 2.5 mm; (vii) 3.0 ± 0.5 mm; (viii) ≤ 10.0 mm; (ix) ≤ 9.0 mm; (x) ≤ 8.0 mm; (xi) ≤ 7.0 mm; (xii) ≤ 6.0 mm; (xiii) 5.0 ± 0.5 mm; and (xiv) 4-6 mm.

Preferably, the length of the first ion guide and/or the second ion guide is selected from the group comprising: (i) ≥ 100 mm; (ii) ≥ 120 mm; (iii) ≥ 150 mm; (iv) 130 ± 10 mm; (v) 100-150 mm; (vi) ≤ 160 mm; (vii) ≤ 180 mm; (viii) ≤ 200 mm; (ix) 130-150 mm; (x) 120-180 mm; (xi) 120-140 mm; (xii) 130 mm ± 5, 10, 15, 20, 25 or 30 mm; (xiii) 50-300 mm; (xiv) 150-300 mm; (xv) ≥ 50 mm; (xvi) 50-100 mm; (xvii) 60-90 mm; (xviii) ≥ 75 mm; (xix) 50-75 mm; and (xx) 75-100 mm.

Preferably, the ion source is an atmospheric pressure ion source such as an Electrospray ("ES") or Atmospheric Pressure Chemical Ionisation ("APCI") ion source. According to a less preferred embodiment, the ion source may be a Matrix Assisted Laser Desorption Ionisation ("MALDI") ion source.

Preferably, the mass analyser is either a time-of-flight mass analyser, preferably an orthogonal time of flight mass analyser or a quadrupole mass analyser. According to a less preferred embodiment, a quadrupole ion trap may be provided as the mass analyser.

According to a second aspect of the present invention, there is provided a mass spectrometer as claimed in claim 14.

An ion guide according to the preferred embodiment may comprise at least 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95 or 100 ring electrodes.

According to a third aspect of the present invention, there is provided a mass spectrometer as claimed in claim 16.

Preferably, the ring electrodes of the first ion guide are maintained at substantially the same dc potential, further preferably 0-1 V dc above the potential of the differential pumping aperture.

Preferably, the ring electrodes of the second ion guide are maintained at substantially the same dc voltage, further preferably 0-1 V dc below the potential of the differential pumping aperture.

According to a fourth aspect of the present invention, there is provided a mass spectrometer as claimed in claim 19.

According to a fifth aspect of the present invention, there is provided a method of mass spectrometry as claimed in claim 20.

According to a sixth aspect of the present invention, there is provided a mass spectrometer as claimed in claim 21.

Preferably, $\geq$ 50%, further preferably $\geq$ 60%, $\geq$ 70%, $\geq$ 80%, $\geq$ 90% or 100% of the ring electrodes have substantially circular internal apertures and the diameter of the internal apertures is selected from the group comprising: (i) 1.0 $\pm$ 0.5 mm; (ii) 2.0 $\pm$ 0.5 mm; (iii) 3.0 $\pm$ 0.5 mm; (iv) 4.0 $\pm$ 0.5 mm; (v) 5.0 $\pm$ 0.5 mm;

(vi) 6.0 ± 0.5 mm; (vii) 7.0 ± 0.5 mm; (viii) 8.0 ± 0.5 mm; (ix) 9.0 ± 0.5 mm; (x) 10.0 ± 0.5 mm; and (xi) < 10 mm.

Preferably, the ion guide has an overall length selected from the group comprising: (i) ≥ 10 cm; (ii) 10-15 cm; (iii) 13.0 ± 1.0 cm; (iv) 15-20 cm; (v) ≥ 20 cm; and (vi) 5-20 cm.

Preferably, at least a portion of the ion guide is maintained in use in a vacuum chamber at a pressure selected from the group comprising: (i) ≥ 0.1 mbar; (ii) ≥ 0.5 mbar; (iii) ≥ 1.0 mbar; (iv) ≥ 1.5 mbar; (v) ≥ 2.0 mbar; (vi) ≥ 2.5 mbar; (vii) ≥ 3.0 mbar; (viii) ≥ 3.5 mbar; (ix) ≥ 4.0 mbar; (x) ≥ 4.5 mbar; (xi) ≥ 5.0 mbar; (xii) ≥ 6.0 mbar; (xiii) ≥ 7.0 mbar; (xiv) ≥ 8.0 mbar; (xv) ≥ 9.0 mbar; (xvi) ≥ 10 mbar; (xvii) ≤ 20 mbar; and (xviii) ≤ 30 mbar.

According to a seventh aspect of the present invention, there is provided a method of mass spectrometry as claimed in claim 25.

According to a eighth aspect of the present invention, there is provided a mass spectrometer as claimed in claim 26.

According to a ninth aspect of the present invention, there is provided a mass spectrometer as claimed in claim 27.

According to a tenth aspect of the present invention, there is provided a mass spectrometer as claimed in claim 28.

According to an eleventh aspect of the present invention, there is provided a mass spectrometer as claimed in claim 29.

According to a twelfth aspect of the present invention, there is provided a mass spectrometer as claimed in claim 30.

According to a thirteenth aspect of the present invention, there is provided a mass spectrometer as claimed in claim 31.

Preferably, the first vacuum chamber is arranged

and adapted to be maintained at a pressure ≥ 1 mbar.

Preferably, the second vacuum chamber is arranged and adapted to be maintained at a pressure 10^{-3}-10^{-2} mbar.

Preferably, the potential difference between the ion guides is ≤ 5 V dc, further preferably ≤ 2 V dc, further preferably ≤ 1 V dc.

Preferably, the ring electrodes in an ion guide are maintained at substantially the same dc potential.

Preferably, the ring electrodes are relatively thin e.g. ≤ 2 mm, further preferably ≤ 1 mm, further preferably 0.5 ± 0.2 mm, further preferably 0.7 ± 0.1 mm thick. According to a particularly preferred embodiment the ring electrodes are between 0.5-0.7 mm thick in contrast to multipole rod sets which are typically > 10 cm long.

Various embodiments of the present invention will now be described, by way of example only, and with reference to the accompanying drawings in which:

Fig. 1 shows a preferred ion tunnel arrangement;

Fig. 2 shows a conventional mass spectrometer with an atmospheric pressure ion source and two rf hexapole ion guides disposed in separate vacuum chambers;

Fig. 3 shows an embodiment of the present invention wherein one of the hexapole ion guides has been replaced with an ion tunnel; and

Fig. 4 shows another embodiment of the present invention wherein both hexapole ion guides have been replaced with ion tunnels.

As shown in Fig. 1, a preferred ion tunnel 15 comprises a plurality of ring electrodes 15a,15b. Adjacent ring electrodes 15a,15b are connected to different phases of an rf power supply. For example, the first, third, fifth etc. ring electrodes 15a may be connected to the 0° phase supply 16a, and the second, fourth, sixth etc. ring electrodes 15b may be connected to the 180° phase supply 16b. Ions from an ion source pass through the ion tunnel 15 and are efficiently transmitted by it. In contrast to ion funnels,

preferably all of the ring electrodes 15a,15b are maintained at substantially the same dc voltage/potential. Unlike ion traps, blocking dc potentials are not applied to either the entrance or exit of the ion tunnel. Instead, all the ring electrodes are maintained at substantially the same dc potential during operation, preferably by connecting all the ring electrodes to a common dc voltage supply.

Fig. 2 shows a conventional mass spectrometer. An Electrospray ("ES") ion source 1 or an Atmospheric Pressure Chemical Ionisation ("APCI") 1,2 ion source emits ions which enter a first vacuum chamber 17 pumped by a rotary or mechanical pump 4 via a sample cone 3 and a portion of the gas and ions passes through a first differential pumping aperture 21 preferably maintained at 50-120V into a second vacuum chamber 18 housing a first rf-only hexapole ion guide 6. The second vacuum chamber 18 is pumped by a rotary or mechanical pump 7. Ions are transmitted by the first rf-only hexapole ion guide 6 through the second vacuum chamber 18 and pass through a second differential pumping aperture 8 into a third vacuum chamber 19 pumped by a turbo-molecular pump 10. The third vacuum chamber 19 houses a second rf-only hexapole ion guide 9. Ions are transmitted by the second rf-only hexapole ion guide 9 through the third vacuum chamber 19 and pass through a third differential pumping aperture 11 into a fourth vacuum chamber 20 which is pumped by a turbo-molecular pump 14. The fourth vacuum chamber 20 houses a prefilter rod set 12, a first quadrupole mass filter/analyser 13 and may include other elements such as a collision cell (not shown), a second quadrupole mass filter/analyser together with an ion detector (not shown) or a time of flight analyser (not shown).

Fig. 3 illustrates an embodiment of the present invention wherein the first hexapole ion guide 6 has been replaced with an ion tunnel 15 according to the preferred embodiment. The other components of the mass

spectrometer are substantially the same as described in relation to Fig. 2 and hence will not be described again. The ion tunnel 15 exhibits an improved transmission efficiency of approximately 25% compared with using the first hexapole ion guide 6 and the ion tunnel 15 does not suffer from as narrow a m/z bandpass transmission efficiency which is inherent with ion funnels. An rf-voltage is applied to the ring electrodes and the ion tunnel 15 is preferably maintained at 0-2 V dc above the dc potential of the third differential pumping aperture 11 which is preferably at ground (0 V dc) when two quadrupole mass filters/analysers are provided in the fourth vacuum chamber 20 or around 40-240 V dc if a time of flight mass analyser is used instead of a second quadrupole mass analyser. However, as will be appreciated by those skilled in the art the third differential pumping aperture may be maintained at other dc potentials.

As will also be appreciated by those skilled in the art, although an rf voltage and a dc potential are applied to the ring electrodes 15a,15b, the ion tunnel 15 is nonetheless referred to as being an "rf-only" ion guide since all the ring electrodes 15a,15b are maintained at substantially the same dc potential (in contrast to a quadrupole mass filter wherein different rod electrodes are maintained at different dc potentials).

In another less preferred (unillustrated) embodiment, the second hexapole ion guide 9 may be replaced by an ion tunnel 15' with the first hexapole ion guide 6 being maintained.

Fig. 4 shows a particularly preferred embodiment of the present invention wherein both the first hexapole ion guide 6 and the second hexapole ion guide 9 have been replaced with ion tunnels 15,15'. The ion tunnels 15,15' are about 13 cm in length and preferably comprise approximately 85 ring electrodes. The ion tunnel 15 in the second vacuum chamber 18 is preferably maintained at

a pressure ≥ 1 mbar and is supplied with an rf-voltage at a frequency ~ 1 MHz, and the ion tunnel 15' in the third vacuum chamber 19 is preferably maintained at a pressure of 10^{-3}-10^{-2} mbar and is supplied with an rf-voltage at a frequency ~ 2 MHz. Rf frequencies of 800 kHz - 3 MHz could also be used for both ion tunnels 15,15' according to further embodiments of the present invention. The individual ring electrodes in each ion tunnel 15,15' preferably have a circular aperture which is approximately 3-5 mm in diameter.

According to the preferred embodiment if an ion tunnel 15' is provided in the third vacuum chamber 19, then the ring electrodes 15a,15b are preferably maintained at around 0-2 V dc above the dc potential of the third differential pumping aperture 11 which is preferably at either at ground (0 V dc) or at 40-240 V dc, although according to less preferred embodiments the third differential pumping aperture 11 may be maintained at other dc potentials. If an ion tunnel 15 is provided in the second vacuum chamber 18 then the ring electrodes 15a,15b are also preferably maintained at around 0-2 V dc above the dc potential of the third differential pumping aperture 11.

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Claims

1. A mass spectrometer comprising:

a continuous ion source for producing ions;

a first vacuum chamber comprising a first rf-only ion guide comprising a first plurality of ring electrodes, each ring electrode having an internal aperture;

a second vacuum chamber downstream of said first vacuum chamber and separated therefrom by a first differential pumping aperture;

a third vacuum chamber downstream of said second vacuum chamber and separated therefrom by a second differential pumping aperture, said third vacuum chamber comprising a mass analyser;

characterised in that:

at least 90%, preferably 100%, of said first plurality of ring electrodes have substantially the same size internal aperture; and

at least 90%, preferably 100%, of said first plurality of ring electrodes are arranged and adapted to be maintained at substantially the same dc voltage or are connected to a common dc voltage supply.

2. A mass spectrometer as claimed in claim 1, further comprising a second rf-only ion guide disposed in said second vacuum region, said second ion guide comprising a second plurality of ring electrodes.

3. A mass spectrometer as claimed in claim 2, wherein at least 90%, preferably 100%, of said second plurality of ring electrodes have substantially the same size internal apertures and/or are arranged and adapted to be maintained at substantially the same dc voltage or are connected to a common dc voltage supply.

4. A mass spectrometer as claimed in claim 1, 2 or 3, wherein said first and/or second ion guides comprise at least 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, 60, 70, 80, 90 or 100 ring electrodes.

5. A mass spectrometer as claimed in any preceding claim, wherein said first ion guide is maintained at 0-2 V dc, preferably 0-1 V dc, above the dc potential of said first differential pumping aperture.

6. A mass spectrometer as claimed in any preceding claim when dependent upon claim 2, wherein said second ion guide is maintained at 0-2 V dc, preferably 0-1 V dc, above the dc potential of said second differential pumping aperture.

7. A mass spectrometer as claimed in any preceding claim, wherein the pressure in said first vacuum chamber is selected from the group comprising: (i) ≥ 0.5 mbar; (ii) ≥ 0.7 mbar; (iii) ≥ 1.0 mbar; (iv) ≥ 1.3 mbar; (v) ≥ 1.5 mbar; (vi) ≥ 2.0 mbar; (vii) ≥ 5.0 mbar; (viii) ≥ 10.0 mbar; (ix) 1-5 mbar; (x) 1-2 mbar; and (xi) 0.5-1.5 mbar.

8. A mass spectrometer as claimed in any preceding claim, wherein the pressure in said second vacuum chamber is selected from the group comprising: (i) 10^{-3}-10^{-2} mbar; (ii) ≥ 2 x 10^{-3} mbar; (iii) ≥ 5 x 10^{-3} mbar; (iv) ≤ 10^{-2} mbar; (v) 10^{-3}-5 x 10^{-3} mbar; and (vi) 5 x 10^{-3}-10^{-2} mbar.

9. A mass spectrometer as claimed in any preceding claim, wherein said first plurality and/or said second plurality of ring electrodes have internal diameters or dimensions selected from the group comprising: (i) ≤ 5.0 mm; (ii) ≤ 4.5 mm; (iii) ≤ 4.0 mm; (iv) ≤ 3.5 mm; (v) ≤ 3.0 mm; (vi) ≤ 2.5 mm; (vii) 3.0 ± 0.5 mm; (viii) ≤ 10.0 mm; (ix) ≤ 9.0 mm; (x) ≤ 8.0 mm; (xi) ≤ 7.0 mm; (xii) ≤

6.0 mm; (xiii) 5.0 ± 0.5 mm; and (xiv) 4-6 mm.

10. A mass spectrometer as claimed in any preceding claim, wherein the length of said first ion guide and/or said second ion guide is selected from the group comprising: (i) ≥ 100 mm; (ii) ≥ 120 mm; (iii) ≥ 150 mm; (iv) 130 ± 10 mm; (v) 100-150 mm; (vi) ≤ 160 mm; (vii) ≤ 180 mm; (viii) ≤ 200 mm; (ix) 130-150 mm; (x) 120-180 mm; (xi) 120-140 mm; (xii) 130 mm ± 5, 10, 15, 20, 25 or 30 mm; (xiii) 50-300 mm; (xiv) 150-300 mm; (xv) ≥ 50 mm; (xvi) 50-100 mm; (xvii) 60-90 mm; (xviii) ≥ 75 mm; (xix) 50-75 mm; and (xx) 75-100 mm.

11. A mass spectrometer as claimed in any preceding claim, wherein said ion source is an atmospheric pressure ion source.

12. A mass spectrometer as claimed in claim 11, wherein said ion source is an Electrospray ("ES") ion source or an Atmospheric Pressure Chemical Ionisation ("APCI") ion source.

13. A mass spectrometer as claimed in any preceding claim, wherein said mass analyser is selected from the group comprising: (i) a time-of-flight mass analyser, preferably an orthogonal time of flight mass analyser; (ii) a quadrupole mass analyser; and (iii) a quadrupole ion trap.

14. A mass spectrometer comprising:

a continuous ion source;

an rf-only ion guide provided in a first vacuum chamber for transmitting ions without substantially trapping said ions in said ion guide; and

a mass analyser provided in a second vacuum chamber downstream of said first vacuum chamber;

characterised in that:

said rf-only ion guide comprises a plurality of

ring electrodes having substantially the same size internal diameter, aperture or aperture area and maintained at substantially the same dc voltage; and

said first vacuum chamber comprises an entrance aperture, an exit aperture, and a port connected to a vacuum pump and is otherwise substantially gas tight.

15. A mass spectrometer as claimed in claim 14, wherein said ion guide comprises at least 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95 or 100 ring electrodes.

16. A mass spectrometer comprising:

an ion source, preferably an Electrospray ("ES"), Atmospheric Pressure Chemical Ionisation ("APCI") or Matrix Assisted Laser Desorption Ionisation ("MALDI") ion source;

a first rf-only ion guide disposed in a first vacuum chamber pumped by a first vacuum pump, said first ion guide comprising a plurality of ring electrodes; and

a second rf-only ion guide disposed in a second vacuum chamber pumped by a second vacuum pump, said second vacuum chamber being downstream from said first vacuum chamber and separated therefrom by a differential pumping aperture, said second ion guide comprising a plurality of ring electrodes.

17. A mass spectrometer as claimed in claim 16, wherein the ring electrodes of said first ion guide are maintained at substantially the same dc potential, preferably 0-1 V dc above the potential of said differential pumping aperture.

18. A mass spectrometer as claimed in claim 16 or 17, wherein the ring electrodes of said second ion guide are maintained at substantially the same dc voltage, preferably 0-1 V dc below the potential of said differential pumping aperture.

19. A mass spectrometer comprising:

an ion source;

a first rf only ion guide disposed in a first vacuum chamber, said first ion guide comprising a plurality of ring electrodes maintained, in use, at substantially the same dc voltage; and

a second rf only ion guide disposed in a second vacuum chamber downstream from said first vacuum chamber and separated therefrom by a differential pumping aperture.

20. A method of mass spectrometry, comprising:

providing a continuous ion source;

providing an ion guide for transmitting ions without substantially trapping ions, said ion guide comprising a plurality of ring electrodes in a first vacuum chamber upstream from a second vacuum chamber comprising a mass analyser, at least 90%, preferably 100%, of said ring electrodes having substantially the same internal diameter or aperture size; and

maintaining adjacent ring electrodes at substantially the same dc voltage.

21. A mass spectrometer, comprising:

a non-pulsed ion source;

an ion guide comprising a plurality of ring electrodes, said ring electrodes being maintained in use at substantially the same dc voltage, said ion guide being provided in a first vacuum chamber having an entrance orifice, an exit differential pumping aperture, and a vacuum pump port, and being otherwise substantially gas tight;

a second vacuum chamber downstream from said first vacuum chamber and separated therefrom by said differential pumping aperture; and

a third vacuum chamber downstream from said second vacuum chamber, said third vacuum chamber comprising a mass analyser, preferably a time of flight mass analyser

or a quadrupole mass analyser.

22. A mass spectrometer as claimed in claim 21, wherein ≥ 50%, preferably ≥ 60%, ≥ 70%, ≥ 80%, ≥ 90% or 100% of said ring electrodes have substantially circular internal apertures and wherein the diameter of said internal apertures is selected from the group comprising: (i) 1.0 ± 0.5 mm; (ii) 2.0 ± 0.5 mm; (iii) 3.0 ± 0.5 mm; (iv) 4.0 ± 0.5 mm; (v) 5.0 ± 0.5 mm; (vi) 6.0 ± 0.5 mm; (vii) 7.0 ± 0.5 mm; (viii) 8.0 ± 0.5 mm; (ix) 9.0 ± 0.5 mm; (x) 10.0 ± 0.5 mm; and (xi) < 10 mm.

23. A mass spectrometer as claimed in claim 21 or 22, wherein said ion guide has an overall length selected from the group comprising: (i) ≥ 10 cm; (ii) 10-15 cm; (iii) 13.0 ± 1.0 cm; (iv) 15-20 cm; (v) ≥ 20 cm; and (vi) 5-20 cm.

24. A mass spectrometer as claimed in claim 21, 22 or 23, wherein at least a portion of said ion guide is maintained in use in a vacuum chamber at a pressure selected from the group comprising: (i) ≥ 0.1 mbar; (ii) ≥ 0.5 mbar; (iii) ≥ 1.0 mbar; (iv) ≥ 1.5 mbar; (v) ≥ 2.0 mbar; (vi) ≥ 2.5 mbar; (vii) ≥ 3.0 mbar; (viii) ≥ 3.5 mbar; (ix) ≥ 4.0 mbar; (x) ≥ 4.5 mbar; (xi) ≥ 5.0 mbar; (xii) ≥ 6.0 mbar; (xiii) ≥ 7.0 mbar; (xiv) ≥ 8.0 mbar; (xv) ≥ 9.0 mbar; (xvi) ≥ 10 mbar; (xvii) ≤ 20 mbar; and (xviii) ≤ 30 mbar.

25. A method of mass spectrometry comprising:

providing a non-pulsed ion source;

providing an ion guide for guiding ions without substantially trapping said ions, said ion guide comprising a plurality of ring electrodes in a vacuum chamber, said ion guide having a length L and being maintained in said vacuum chamber at a pressure P, wherein the pressure-length product p x L is selected from the group comprising: (i) ≥ 1 mbar cm; (ii) ≥ 2

mbar cm; (iii) ≥ 5 mbar cm; (iv) ≥ 10 mbar cm; (v) ≥ 15 mbar cm; (vi) ≥ 20 mbar cm; (vii) ≥ 25 mbar cm; (viii) ≥ 30 mbar cm; (ix) ≥ 40 mbar cm; (x) ≥ 50 mbar cm; (xi) ≥ 60 mbar cm; (xii) ≥ 70 mbar cm; (xiii) ≥ 80 mbar cm; (xiv) ≥ 90 mbar cm; (xv) ≥ 100 mbar cm; (xvi) ≥ 110 mbar cm; (xvii) ≥ 120 mbar cm; (xviii) ≥ 130 mbar cm; (xix) ≥ 140 mbar cm; (xx) ≥ 150 mbar cm; (xxi) ≥ 160 mbar cm; (xxii) ≥ 170 mbar cm; (xxiii) ≥ 180 mbar cm; (xxiv) ≥ 190 mbar cm; and (xxv) ≥ 200 mbar cm; and

maintaining ≥ 80%, preferably ≥ 90%, further preferably 100%, of said ring electrodes at substantially the same dc voltage, preferably 1-12 V dc or 40-242 V dc.

26. A mass spectrometer comprising:

a non-pulsed ion source, preferably an Electrospray ("ES") or Atmospheric Pressure Chemical Ionisation ("APCI") ion source;

a first vacuum chamber;

a first ring electrode ion guide comprising a plurality of ring electrodes disposed in said first vacuum chamber wherein said first ring electrode ion guide is arranged to transmit ions without substantially inducing collisional induced decomposition/dissociation ("CID") of said ions, said ring electrodes being maintained at substantially the same dc voltage;

a second vacuum chamber downstream of said first vacuum chamber and separated therefrom by a differential pumping aperture, said first and second vacuum chambers being pumped by separate vacuum pumps;

a second ion guide disposed in said second vacuum chamber, preferably a second ring electrode ion guide;

a quadrupole or time of flight mass analyser disposed downstream of said second ion guide; and

wherein said first ion guide is maintained at a pressure ≥ 1 mbar.

27. A mass spectrometer comprising:

an Electrospray ("ES") or Atmospheric Pressure Chemical Ionisation ("APCI") ion source for providing a beam of ions;

a first vacuum chamber pumped by a first vacuum pump arranged to maintain the pressure in said first vacuum chamber at ≥ 1 mbar, said first vacuum chamber comprising an inlet for receiving ions from said ion source and housing a first ion guide comprising a first plurality of ring electrodes;

means for supplying an rf voltage to said first ion guide and for maintaining said first plurality of ring electrodes at substantially the same dc potential, preferably 0-2 V dc;

a second vacuum chamber downstream from said first vacuum chamber and separated therefrom by a first differential pumping aperture, said second vacuum chamber pumped by a second vacuum pump arranged to maintain the pressure in said second vacuum chamber at 10^{-3}-10^{-2} mbar, said second vacuum chamber housing a second ion guide comprising a second plurality of ring electrodes;

means for supplying an rf voltage to said second ion guide and for maintaining said second plurality of ring electrodes at substantially the same dc potential, preferably 0-2 V dc;

a third vacuum chamber downstream from said second vacuum chamber and separated therefrom by a second differential pumping aperture, said third vacuum chamber pumped by a third vacuum pump and housing at least a first quadrupole mass filter/analyser, a collision cell preferably a hexapole collision cell, a second quadrupole mass filter/analyser and an ion detector.

28. A mass spectrometer comprising:

an Electrospray ("ES") or Atmospheric Pressure Chemical Ionisation ("APCI") ion source for providing a beam of ions;

a first vacuum chamber pumped by a first vacuum pump arranged to maintain the pressure in said first vacuum chamber at ≥ 1 mbar, said first vacuum chamber comprising an inlet for receiving ions from said ion source and housing a first ion guide comprising a first plurality of ring electrodes;

means for supplying an rf voltage to said first ion guide and for maintaining said first plurality of ring electrodes at substantially the same dc potential, preferably 40-242 V dc;

a second vacuum chamber downstream from said first vacuum chamber and separated therefrom by a first differential pumping aperture, said second vacuum chamber pumped by a second vacuum pump arranged to maintain the pressure in said second vacuum chamber at 10^{-3}-10^{-2} mbar, said second vacuum chamber housing a second ion guide comprising a second plurality of ring electrodes;

means for supplying an rf voltage to said second ion guide and for maintaining said second plurality of ring electrodes at substantially the same dc potential, preferably 40-242 V dc;

a third vacuum chamber downstream from said second vacuum chamber and separated therefrom by a second differential pumping aperture, said third vacuum chamber pumped by a third vacuum pump and housing a quadrupole mass filter/analyser and a collision cell preferably a hexapole collision cell; and

a fourth vacuum chamber downstream from said third vacuum chamber, said fourth vacuum chamber housing a time of flight mass analyser, preferably an orthogonal acceleration time of flight mass analyser, wherein the entrance aperture to said fourth vacuum chamber is preferably maintained at a dc potential ~ 0V dc.

29. A mass spectrometer comprising:

a Matrix Assisted Laser Desorption Ionisation ("MALDI") ion source;

a first vacuum chamber comprising an ion guide comprising ≥ 10 ring electrodes; and

a second vacuum chamber downstream of said first vacuum chamber and separated therefrom by a differential pumping aperture, said second vacuum chamber comprising an ion guide comprising ≥ 10 ring electrodes.

30. A mass spectrometer comprising:

an Electrospray ("ES") ion source;

a first vacuum chamber comprising an ion guide comprising ≥ 10 ring electrodes; and

a second vacuum chamber downstream of said first vacuum chamber and separated therefrom by a differential pumping aperture, said second vacuum chamber comprising an ion guide comprising ≥ 10 ring electrodes.

31. A mass spectrometer comprising:

an Atmospheric Pressure Chemical Ionisation ("APCI") ion source;

a first vacuum chamber comprising an ion guide comprising ≥ 10 ring electrodes; and

a second vacuum chamber downstream of said first vacuum chamber and separated therefrom by a differential pumping aperture, said second vacuum chamber comprising an ion guide comprising ≥ 10 ring electrodes.

32. A mass spectrometer as claimed in claim 29, 30 or 31, wherein said first vacuum chamber is arranged and adapted to be maintained at a pressure ≥ 1 mbar.

33. A mass spectrometer as claimed in any of claims 29-32, wherein said second vacuum chamber is arranged and adapted to be maintained at a pressure 10^{-3}-10^{-2} mbar.

34. A mass spectrometer as claimed in any of claims 29-33, wherein the potential difference between said ion guides is ≤ 5 V dc, preferably ≤ 2 V dc, preferably ≤ 1 V dc.

35. A mass spectrometer as claimed in any of claims 29-34, wherein the ring electrodes in an ion guide are maintained at substantially the same dc potential or are connected to a common dc voltage supply.

36. A mass spectrometer as claimed in any of claims 29-35, wherein said ring electrodes are ≤ 2 mm, preferably ≤ 1 mm, preferably 0.5 ± 0.2 mm, preferably 0.7 ± 0.1 mm thick.

ABSTRACT

MASS SPECTROMETERS AND METHODS OF MASS SPECTROMETRY

An ion guide 15;15' is disclosed comprising a plurality of ring electrodes 15a,15b each having substantially the same size internal aperture. The ring electrodes 15a,15b are maintained at substantially the same dc voltage by e.g. connecting them to a common dc voltage supply. According to a particularly preferred embodiment two ring electrode ion guides 15,15' are provided in two separate vacuum chambers 18,19.

[Fig. 4]

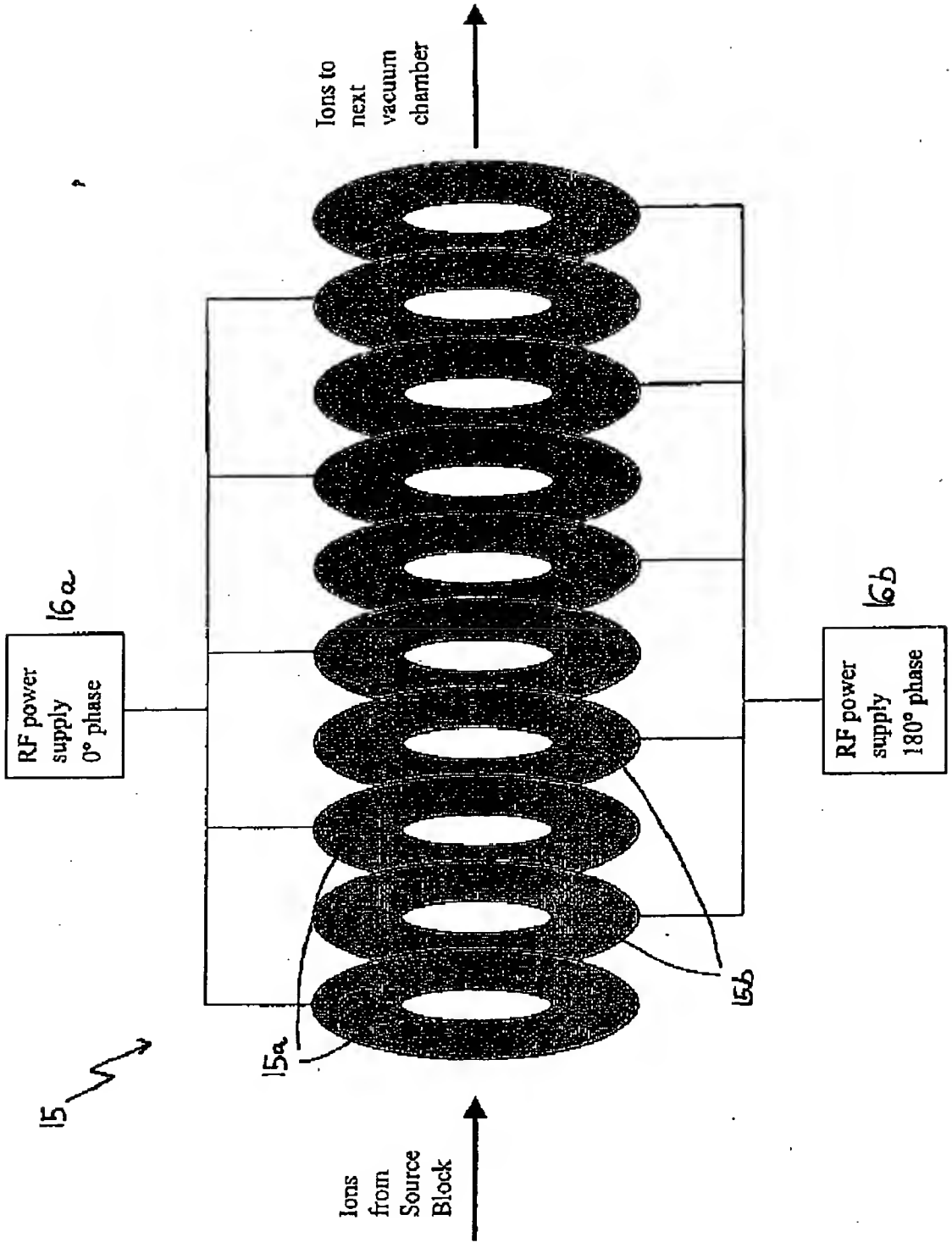
Ions to next vacuum chamber
RF power supply 0° phase
16a
RF power supply 180° phase
16b
15
15a
15b
Ions from Source Block

Fig. 1

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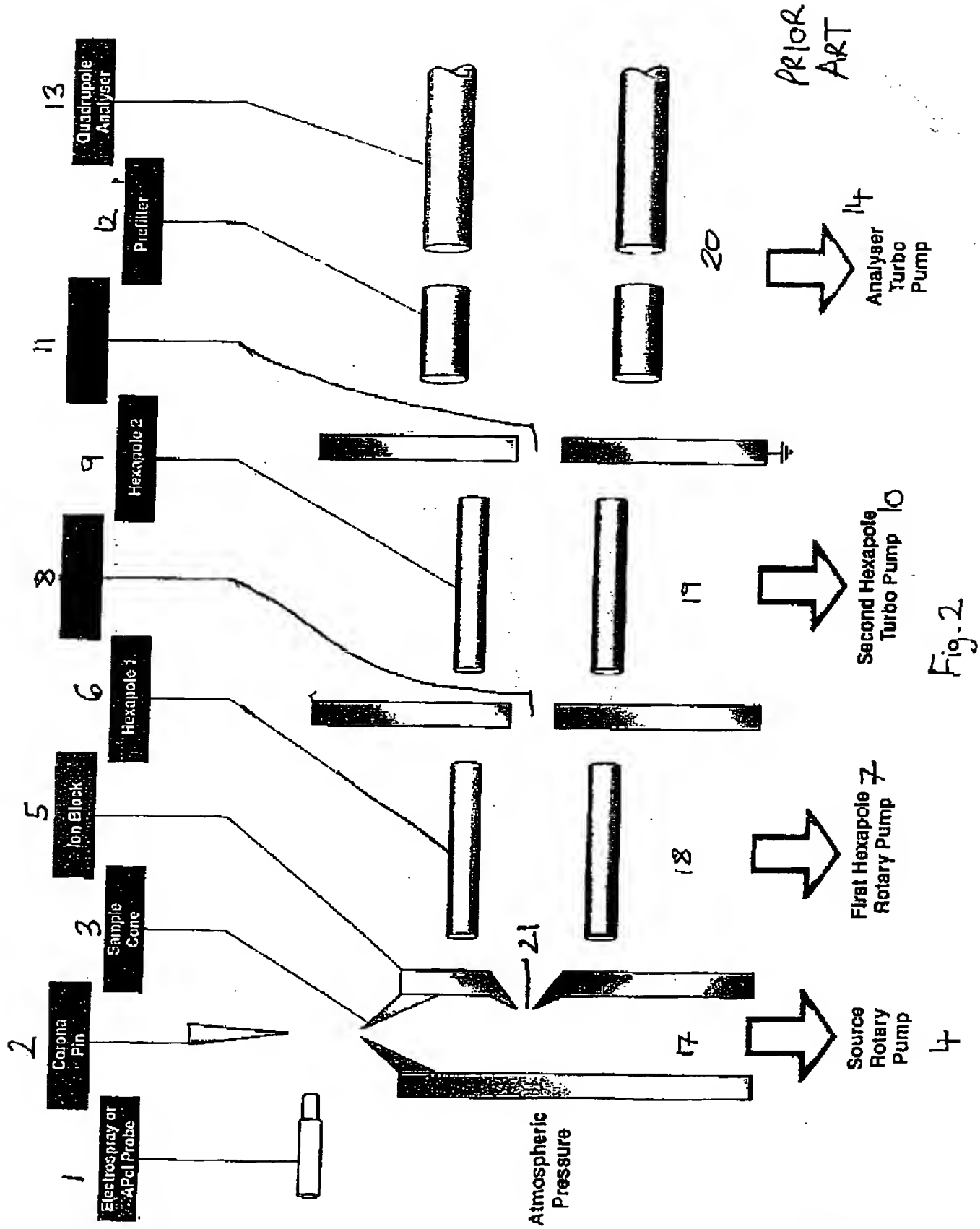

Fig. 2

3/4

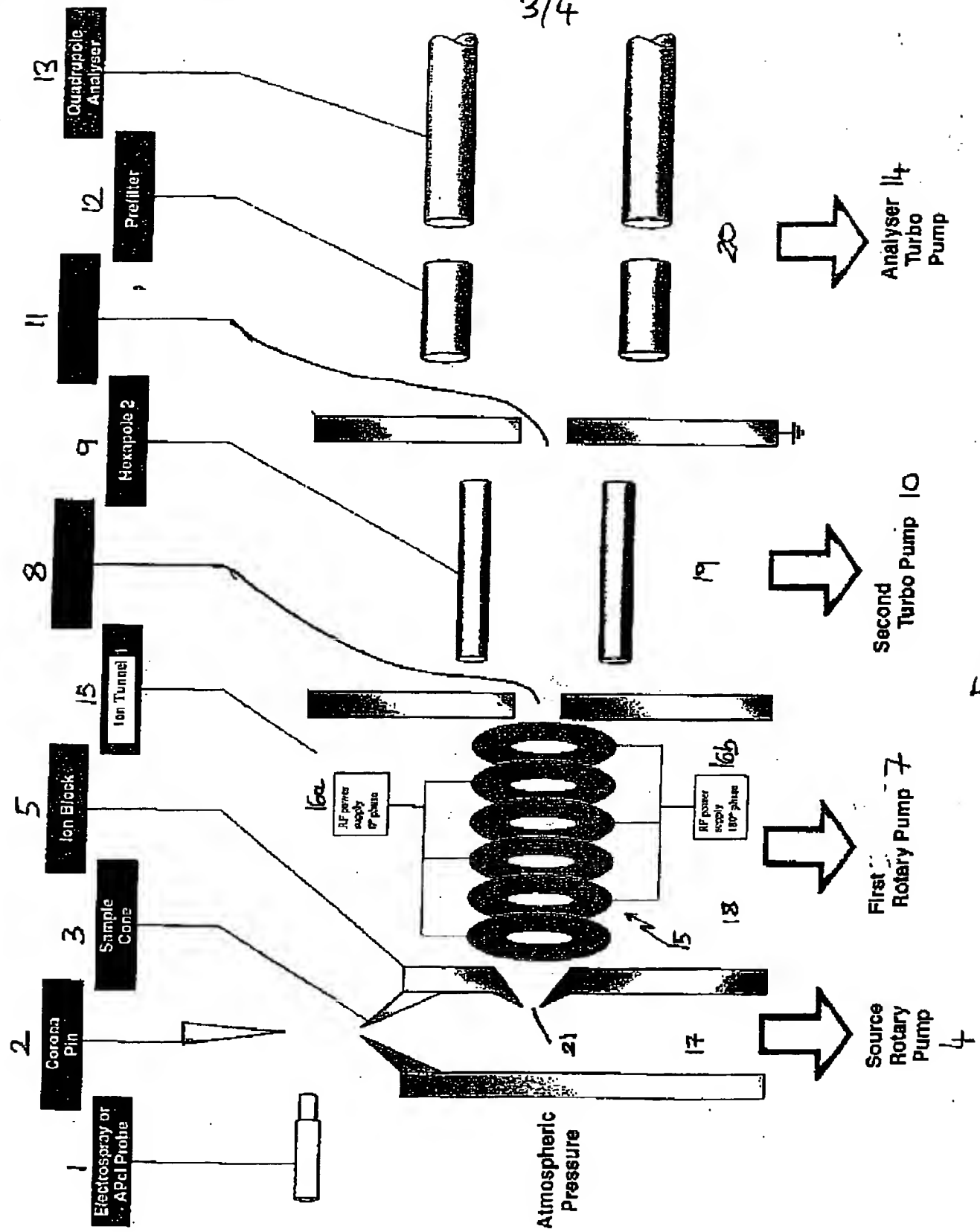
13
Quadrupole Analyser
12
Prefilter
11
9
Hexapole 2
8
15
Ion Tunnel 1
5
Ion Block
3
Sample Cone
2
Corona Pin
1
Electrospray or APcI Probe
Atmospheric Pressure
16a
RF power supply 0° phase
16b
RF power supply 180° phase
21
17
18
20
Analyser Turbo Pump 14
19
Second Turbo Pump 10
First Rotary Pump 7
Source Rotary Pump 4

Fig.3

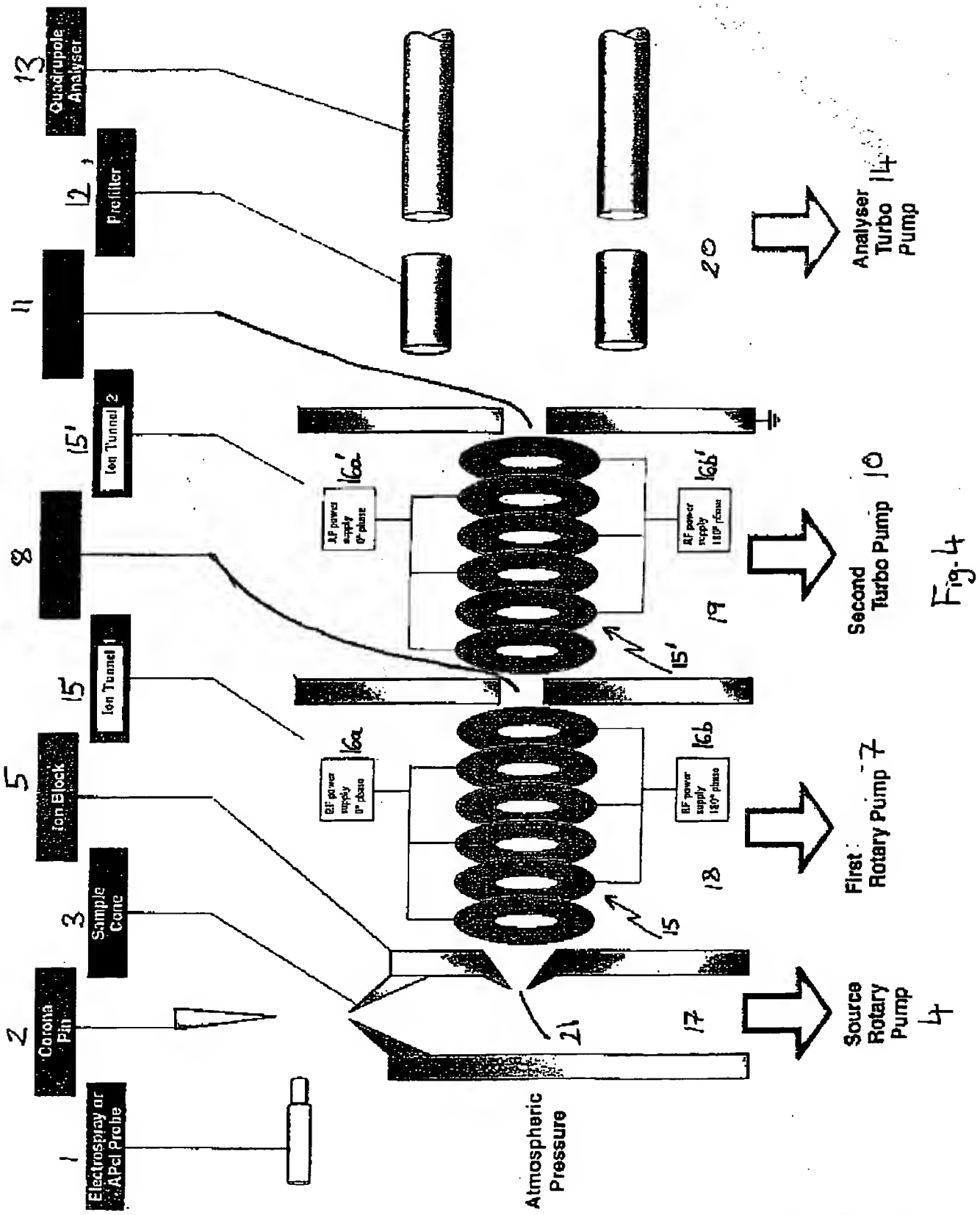
Electrospray or APci Probe
1
Corona Pin
2
Sample Cone
3
Ion Block
5
Ion Tunnel 1
15
8
Ion Tunnel 2
15'
11
Prefilter
12
Quadrupole Analyser
13
Atmospheric Pressure
21
16a
16b
16a'
16b'
RF power supply 0° phase
RF power supply 180° phase
17
18
19
20
Source Rotary Pump 4
First Rotary Pump 7
Second Turbo Pump 10
Analyser Turbo Pump 14

Fig. 4